

# Land Application of Carbonatic Lake-Dredged Materials: Effects on Soil Quality and Forage Productivity

Gilbert C. Sigua,\* Samuel W. Coleman, and Mike L. Holtkamp

## ABSTRACT

The ability to reuse carbonatic lake-dredged materials (CLDM) for agricultural purposes is important because it reduces offshore disposal and provides an alternative to disposal of the materials in landfills that are already overtaxed. A four-year (2001 to 2005) study on land application of CLDM as an option for disposal was conducted on a beef cattle pasture in south central Florida. The objectives of this study were (i) to assess CLDM as a soil amendment to improve quality of sandy soils in most subtropical beef cattle pastures and (ii) to determine the effect of CLDM on productivity and nutritive values of bahiagrass (BG, *Paspalum notatum* Flüggé) in subtropical beef cattle pasture. The five treatment combinations arranged in randomized complete block design were represented by plots with different ratios (R) of natural soil (NS) to CLDM: R1 (1000 g kg<sup>-1</sup>:0 g kg<sup>-1</sup>); R2 (750 g kg<sup>-1</sup>:250 g kg<sup>-1</sup>); R3 (500 g kg<sup>-1</sup>:500 g kg<sup>-1</sup>); R4 (250 g kg<sup>-1</sup>:750 g kg<sup>-1</sup>); and R5 (0 g kg<sup>-1</sup>:1000 g kg<sup>-1</sup>). Addition of CLDM had significant ( $p \leq 0.001$ ) effects on soil quality and favorable influence on forage establishment and nutritive values. Compared with the control plots (0 g kg<sup>-1</sup>), the soils in plots amended with CLDM exhibited (i) lower penetration resistance, (ii) an increase in soil pH and exchangeable cations (Ca and Mg), and (iii) decrease in the levels of soil trace metals (Mn, Cu, Fe, Zn, and Si). Results disclosed consistently and significantly ( $p \leq 0.001$ ) higher BG biomass production (forage yield =  $-106.3x^2 + 1015.8x - 39.2$ ;  $R^2 = 0.99^{**}$ ) and crude protein content (CP =  $1.24x + 6.48$ ;  $R^2 = 0.94^{**}$ ) from plots amended with CLDM than those of BG planted on plots with no CLDM treatment.

**D**ISPOSAL AND ENVIRONMENTAL QUALITY of dredged sediments from navigational channels have been judged as beneficial by combinations of physical, chemical, and biological analyses for over 30 yr. However, many people in the scientific community find this approach objectionable since the data does not provide sufficient environmental protection information because several site-specific geochemical and biological factors are typically excluded from the decision-making process (Wenning and Woltering, 2001). The most commonly cited hurdles to using dredged materials beneficially are increased costs, the need for earlier planning and widespread coordination, lack of complementary federal and state regulatory frameworks for evaluating dredged materials as a resource, and a wide-

spread misperception that dredged material is a waste instead of a resource (National Dredging Team, 2003).

Disposal options or better yet, beneficial use of dredged materials is quite challenging. Beneficial use of dredged material must become a national, regional, and local priority, with full support from all levels of government. Current dredged material disposal alternatives have several limitations (Fitzgerald and Pederson, 2001). Options for dealing with dredged materials include leaving them alone, capping them with clean sediments, placing them in confined facilities, disposing of them at upland sites, treating them chemically, or using them for wetlands creation or other beneficial uses (Adams and Pederson, 2001; Krause and McDonnell, 2000; Gambrell et al., 1978). These materials should be regarded as a beneficial resource to be used productively as soil enhancement for agricultural use rather than discarded as spoil materials (Patel et al., 2001; Sigua et al., 2000). The bottom sediment materials from lakes, river, and navigational channels are usually composed of upland soil enriched with nutritive organics.

Environmental impact assessment is an important prerequisite to many dredging initiatives (Sigua et al., 2003; Patel et al., 2001; Sigua et al., 2000). While preliminary efforts are underway to provide information to establish criteria for land disposal, testing procedures for possible land disposal of contaminated sediments are still in their developing stages. Forage production offers an alternative to waste management since nutrients in the waste are recycled into crops that are not directly consumed by humans. Bahiagrass is a good general-use pasture grass that can tolerate a wide range of soil conditions and close grazing, and withstands low fertilizer input (Burson and Watson, 1995; Kidder, 1999). It has the ability to produce moderate yields on soils of very low fertility and is easier to manage than other improved pasture grasses (Chambliss, 1999). Establishment of an excellent, uniform stand of bahiagrass in a short time period is essential and economical. Failure to obtain a good stand early means the loss of not only the initial investment costs, but the production and its cash value (Chambliss, 1999) and often leaves the soil open for erosion. Forage production often requires significant inputs of lime, nitrogen (N) fertilizer, and less frequently of phosphorus (P) and potassium (K) fertilizers. Dredged

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**Abbreviations:** ANOVA, analysis of variance; BG, bahiagrass; CLDM, carbonatic lake-dredged materials; CP, crude protein content; DMRT, Duncan multiple range test; DMY, forage dry matter yield; GLM, general linear model; LP, Lake Panasoffkee; LSD, least significant difference; n, number of samples; NS, natural soils; PEL, probable effects level; SAS, statistical analysis system; SWFWMD, Southwest Florida Water Management District; TEL, threshold effects level; TIN, total inorganic nitrogen; TN, total Kjeldahl nitrogen; TP, total phosphorus.

materials, composted urban plant debris, waste lime, and phosphogypsum are examples of materials that can be used for fertilizing and liming pastures. The sediment removal project in Lake Panasoffkee (LP) is being assessed to determine whether the operation satisfies environmental objectives or expectations. The 19.4-km<sup>2</sup> LP (28°47'40" N, 82°07'56" W), located in Sumter County, Florida has enjoyed excellent water quality due to substantial groundwater flow from Florida's aquifers, but at the same time has lost 324 ha of desirable fisheries habitats due to dissolved Ca carbonates carried by subsurface groundwater, which settles on the bottom and fills in fish spawning areas (Allen, 2000).

There is still much to be learned from this project. Additional research is still needed on disposal options, especially to supply information on criteria testing and evaluation of the physical and chemical impacts of dredged materials at the disposal site. The goal of this research was to explore the beneficial and ecological uses of carbonatic lake-dredged materials as an alternative for commercial liming products in improving the physicochemical properties of existing sandy soils and sustaining forage productivity in subtropical beef cattle pastures. The objectives of this study were: (i) to assess carbonatic lake-dredged materials as a soil amendment to improve quality of sandy soils in most subtropical beef cattle pastures, and (ii) to determine the effect of carbonatic lake-dredged materials on productivity and nutritive values of bahiagrass.

## MATERIALS AND METHODS

### Study Site

The study site is located in Sumter County (Coleman Landing: 28°47'40" N, 82°07'56" W), Florida. The soils at the site were formed from sandy marine or eolian deposits and have a water table depth of 102 to 203 cm for more than 6 mo during most years. These soils are hyperthermic, uncoated typic quartzipsamments (USDA, 1988). The climate of Sumter County is characterized by long, warm, and relatively humid summers and mild, dry winters. The average total annual precipitation (1988 to 2005) in the area was about 1191 mm with approximately half (56%) of this amount occurring during from mid-June through mid-August. The lowest average temperature of 15°C occurs during January. The highest average temperature in the mid- to upper-25°C range occurs regularly from June through September.

### Field Site Preparation

This study encompassed test plots (961 m<sup>2</sup>) adjacent to the Coleman Landing spoil disposal site in Sumter County, FL. Each plot was excavated to a depth of about 28 cm, and existing natural soils (NS) and organic materials were completely removed. Excavated materials were placed at the southern end of the test plots. Existing vegetation from each plot was totally removed before backfilling each plot with different ratios (*R*) of NS and CLDM: R1, (1000 g kg<sup>-1</sup> NS:0 g kg<sup>-1</sup> CLDM); R2, (750 g kg<sup>-1</sup> NS:250 g kg<sup>-1</sup> CLDM); R3, (500 g kg<sup>-1</sup> NS:500 g kg<sup>-1</sup> CLDM); R4, (250 g kg<sup>-1</sup> NS:750 g kg<sup>-1</sup> CLDM); and R5, (0 g kg<sup>-1</sup> NS:1000 g kg<sup>-1</sup> CLDM). Each treatment plot was arranged in completely randomized block design with four replications.

Each plot was backfilled with NS and CLDM that were hauled from the adjacent settling pond. The total amount of CLDM and NS that was placed back on each test plot was in accordance with the different ratios of CLDM and NS that were described above. After mixing the NS and CLDM, each of the test plots was disked to a uniform depth of 28 cm. Plots were disked in an alternate direction until CLDM and NS were uniformly mixed. Each plot was seeded with BG at a rate of 6 kg plot<sup>-1</sup>, followed by dragging a section of chain link fence across each test plot to ensure that BG seeds were in good contact with the mixtures of NS and CLDM. A private laboratory (Flowers Chemical Laboratories) in Leesburg, FL performed the physical and chemical analyses of CLDM that were used in the study. Results and methods of analyses are given in Table 1.

### Soil Sampling and Soil Analyses

Composite samples of soils (0- to 20-cm depth) were taken from each main plot using a steel bucket-type hand auger in 2002 (*n* = 20), 2003 (*n* = 20), 2004 (*n* = 20), and 2005 (*n* = 20). Soil samples were air-dried and passed through a 2-mm mesh sieve before soil chemical extractions. Soil P, exchangeable cations (Ca, Mg, and K), and trace metals (Zn, Mn, Cu, Fe, and Al) were extracted with double acids (0.05 *N* HCl in 0.025 *N* H<sub>2</sub>SO<sub>4</sub>) as described by Mehlich (1953), and analyzed using an inductively coupled plasma spectrophotometer. Soil pH was determined by using 1:2 soils/water ratio (Thomas, 1996). Soils were extracted with 2 *N* KCl for the total inorganic nitrogen (TIN: NO<sub>3</sub>-N + NH<sub>4</sub>-N) determination using an N auto analyzer. Soil chemical analyses were conducted at the University of Florida-Institute of Food and Agricultural Sciences Soil Testing Laboratory, Gainesville, FL.

**Table 1. Selected chemical properties of the dredged materials (*n* = 12) from Lake Panasoffkee.**

Parameter	Unit	Mean	Threshold effect levels (TEL) <sup>†</sup>	Probable effect levels (PEL) <sup>‡</sup>	Analytical method
pH	pH unit	7.8 ± 0.2			EPA150.1
Organic carbon	g kg <sup>-1</sup>	127.0 ± 1.5			EPA9060
Potassium	mg kg <sup>-1</sup>	4.3 ± 1.8			EPA6020
Total phosphorus	mg kg <sup>-1</sup>	1.6 ± 1.2			EPA6010
Total nitrogen	mg kg <sup>-1</sup>	6.9 ± 0.3			EPA351.2
Nitrate-N	mg kg <sup>-1</sup>	0.2 ± 0.05			EPA351.1
Nitrite-N	mg kg <sup>-1</sup>	0.3 ± 0.05			EPA351.1
Ca (as CaCO <sub>3</sub> )	g kg <sup>-1</sup>	828 ± 2.1			ASTM C25-95
Mg (as MgCO <sub>3</sub> )	g kg <sup>-1</sup>	9.0 ± 3.0			ASTM C25-95
Iron	mg kg <sup>-1</sup>	710.0 ± 1.3			EPA6020
Silicon	mg kg <sup>-1</sup>	490.0 ± 1.2			EPA6020
Copper	mg kg <sup>-1</sup>	8.7 ± 1.2	18.7	108	EPA6020
Zinc	mg kg <sup>-1</sup>	7.0 ± 0.6	124	271	EPA6020
Cadmium	mg kg <sup>-1</sup>	2.5 ± 0.1	0.7	4.2	EPA6020
Lead	mg kg <sup>-1</sup>	5.2 ± 1.3	30.2	112	EPA6020
Nickel	mg kg <sup>-1</sup>	14.6 ± 6.4	15.9	42.8	EPA6020
Chromium	mg kg <sup>-1</sup>	40.5 ± 2.1	52.3	160	EPA6020
Arsenic	mg kg <sup>-1</sup>	4.4 ± 0.1	7.2	41.6	EPA6020
Mercury	mg kg <sup>-1</sup>	0.01 ± 0.02	0.1	0.7	EPA7471
Selenium	mg kg <sup>-1</sup>	0.02 ± 0.02			EPA6020
Molybdenum	mg kg <sup>-1</sup>	1.3 ± 0.2			EPA6020

<sup>†</sup> TEL represents the concentrations of sediment-associated contaminants that are not considered to represent significant hazards to aquatic organism (MacDonald, 1994).

<sup>‡</sup> PEL defines the lower limit of the range of contaminant concentrations that are usually or always associated with adverse biological effects (MacDonald, 1994).

### Penetration Resistance Test

Measurements of soil resistance to penetration (0- to 20-cm depth) were taken quarterly ( $n = 80$ ) in 2002, 2003, 2004, and 2005 using the Dickey–John Penetrometer (Dickey–John, Auburn, IL). Soil samples were taken from each site of measurement for moisture content (data were not reported) determination (Gravimetric method). The penetrometer consists of a 30° circular stainless steel cone with a driving shaft and pressure gauge and is designed to mimic a plant root. It has two cones, the first for soft soils with a base diameter of 2.03 cm, and a second for hard soils with a base diameter of 1.28 cm. The driving shaft is graduated every 7.62 cm (3 inches) to allow determination of depth of compaction. The pressure readings are in pounds per square inch (psi). Pressure readings were converted to Pascal unit by multiplying psi values by  $6.9 \times 10^3$ . Pressure units reported in this paper are in Pascal units.

### Plant Sampling and Nutritive Value Analysis

Herbage mass measurements of BG ( $n = 20$  each time) were taken on 2 Apr. 2003, 25 June 2003, 25 Apr. 2004, 25 June 2004, and 20 Mar. 2005 from four sub-plots that were permanently marked, using yellow flags placed at the four corners of a 0.3 by 0.3 m quadrant following the double-ring method of Williams and Hammond (1999). These plots were randomly selected from each main plot. Freshly cut above-ground growth was oven-dried at 60°C for 24 h at the USDA-ARS Laboratory in Brooksville, FL. Plant samples were ground to pass through a 1-mm mesh screen in a Wiley mill. Ground forage was analyzed for crude protein (Gallagher et al., 1976). Herbage crude protein ( $n = 20$ ) contents (CP) were analyzed on 25 June 2003, 25 Apr. 2004, 25 June 2004, and 20 Mar. 2005. Forage samples were predigested in a mixture of nitric and perchloric acids using standard methods (Hanlon and Devore, 1989) and were analyzed for tissue P, K, Ca, Mg, Mn, Cu, Fe, Al, Zn, Pb, and Si concentrations using ICP spectroscopy at the University of Florida Analytical Research Laboratory in Gainesville, FL.

### Data Reduction and Statistical Analysis

The forage yield characteristic of BG in beef cattle pasture was analyzed statistically following the analysis of variance using the SAS PROC GLM model (SAS, 2000). Where the F-test indicated a significant ( $p \leq 0.05$ ) effect, means were separated, following the method of the Duncan multiple range test (DMRT), using appropriate error mean squares (SAS, 2000).

Effects of dredged materials on the crude protein and nutritive values of BG, soil quality, and penetration resistance were analyzed statistically following the PROC ANOVA procedures (SAS, 2000). Where the F-test indicated a significant ( $p \leq 0.05$ ) effect, means were separated, following the method of DMRT, using appropriate mean squares (SAS, 2000).

## RESULTS

### Chemical Properties of Carbonatic Lake-Dredged Materials

The Lake Panasoffkee dredged sediments had high Ca (as  $\text{CaCO}_3$ ) content of  $828 \pm 2.1 \text{ g kg}^{-1}$  (~82%) and an average pH of  $7.8 \pm 0.2$  (Table 1). These carbonatic materials can be considered as a cheaper alternative to liming for pasture establishment and for other agricultural uses. The average Mg content of the dredged

sediment was about  $9.0 \pm 3.0 \text{ g kg}^{-1}$ , whereas OC of the CLDM was about  $127.0 \pm 1.5 \text{ g kg}^{-1}$ . The TP, TN, and K contents of the dredged materials were relatively low with mean concentrations of  $1.6 \pm 1.2$ ,  $6.9 \pm 0.3$ , and  $4.3 \pm 1.8 \text{ mg kg}^{-1}$ , respectively. Average values for Pb, Zn, As, Cu, Hg, Se, and Ni are presented in Table 1. These values were below the threshold effect levels (TEL) and the probable effect levels (PEL) published by the Florida Department of Protection (MacDonald, 1994). The average concentration of Cd ( $2.5 \pm 0.1 \text{ mg kg}^{-1}$ ) was higher than TEL, but lower than PEL. Since the Cd level was below the PEL value, the use of CLDM was still warranted because the Cd level would not result in adverse biological effects (Table 1). TEL represents the concentrations of sediment-associated contaminants that are considered to cause significant hazards to aquatic organisms, whereas PEL represents the higher limit of the range of the contaminant concentrations that are usually or always associated with adverse biological effects. Additionally, the USEPA offers a pollutant concentration limit of the class B sludge for Cd as  $39 \text{ mg kg}^{-1}$ , which is about 10-fold higher than the concentration of Cd in CLDM that were used in the study. Based on the absence of contaminants and the N and P composition of CLDM, these materials can be used as low-grade N and P fertilizers and also as a source of Ca.

### Penetration Resistance

Results show a favorable influence of CLDM on penetration resistance (Fig. 1). The treatment  $\times$  year interaction effect was not significant, but the average penetration resistance varied widely ( $p \leq 0.001$ ) with CLDM application each year. Penetration resistance was lowered significantly as a result of CLDM additions in all years (Fig. 1).

The least compacted soils in all years were observed from plots with  $750 \text{ g kg}^{-1}$  CLDM and mean annual penetration resistances of  $300 \times 10^3$ ,  $500 \times 10^3 \text{ Pa}$ ,  $350 \times 10^3 \text{ Pa}$ , and  $100 \times 10^3 \text{ Pa}$ , respectively. These values, when compared with threshold numbers shown in Fig. 2, would be within the “good” range, thus having high degree of root penetration. The most compacted soils in 2002, 2003, 2004, and 2005 were from the control plots with mean annual penetration resistances of  $1800 \times 10^3$ ,  $1600 \times 10^3$ ,  $1900 \times 10^3$ , and  $1600 \times 10^3 \text{ Pa}$ , respectively. Penetration resistance values of control plots were greater than  $1380 \times 10^3 \text{ Pa}$ . Root penetration decreases linearly with penetration resistance, until almost no roots penetrate into soil, with a penetration resistance of  $1380 \times 10^3 \text{ Pa}$  (Fig. 2). The degree of penetration resistance in the control plots were comparable with the surrounding natural soils (SNS), but were different and significantly higher than those plots with CLDM additions. Overall, penetration resistances in plots applied with CLDM were significantly lower than the control regardless of application rates. This trend was consistent across years. Between plots with no CLDM application and plots with CLDM application (averaged across plots with CLDM), penetration resistance was reduced by

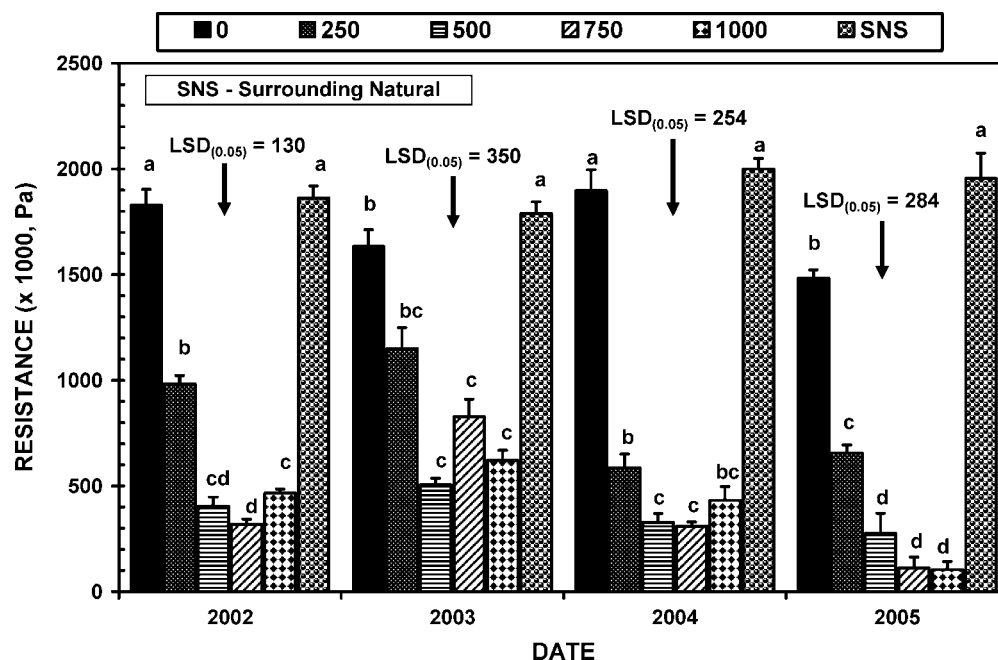


Fig. 1. Penetration resistance in 2002, 2003, 2004, and 2005 for soils with varying levels of dredged materials. Soil penetration resistance from plots with or without CLDM are significantly different ( $p \leq 0.05$ ) in 2002, 2003, 2004, and in 2005 when superscripts located at top of bars are different.

70, 52, 78, and 81% in 2002, 2003, 2004, and 2005, respectively as a result of CLDM application (Fig. 1).

### Soil Chemical Properties

The average soil tests values for pH, TIN, TP, K, Ca, and Mg varied significantly ( $p \leq 0.001$ ) among plots amended with different rates of CLDM within years, but were not affected by the year x treatment interaction effect (Table 2). Compared with the control plots, the

soils in plots amended with CLDM exhibited an increase in soil pH, TIN, Ca, and Mg. However, levels of soil Ca and Mg from plots with CLDM addition were lower in 2005 compared with their average values in 2002, 2003, and 2004. The average Ca levels in soil (averaged across plots with CLDM) in 2002, 2003, and 2004 were 2010, 6503, and 1184  $\text{mg kg}^{-1}$ , respectively, compared with 237  $\text{mg kg}^{-1}$  in 2005.

Addition of CLDM resulted in higher soil pH than those plots with no CLDM. Soil pH (averaged across

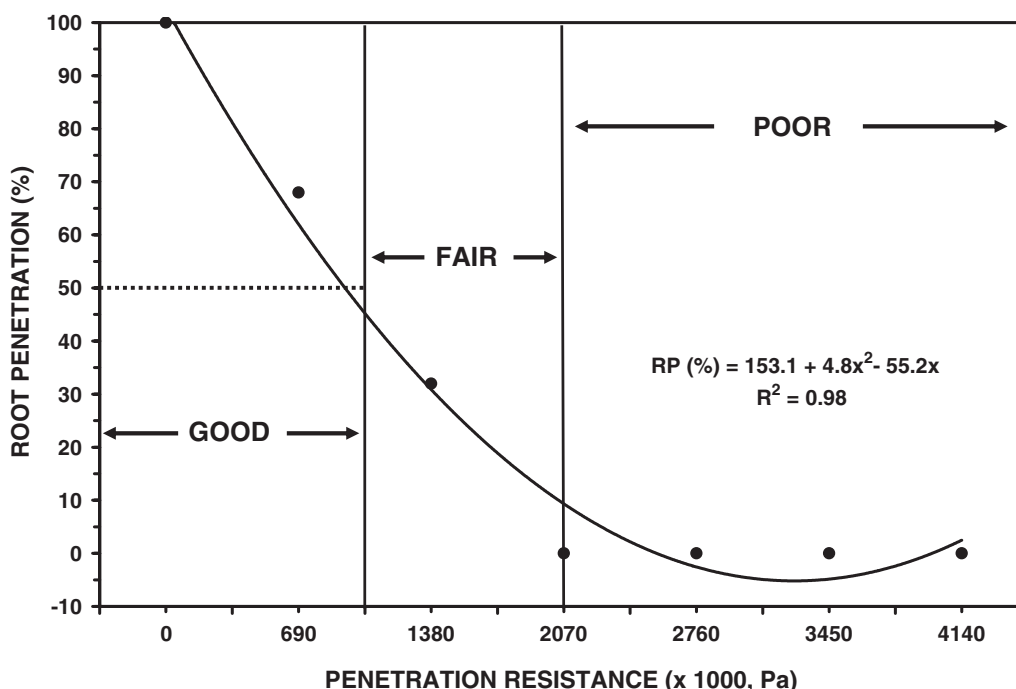


Fig. 2. Relationship between root penetration and penetration resistance in soils using a penetrometer (Murdock et al., 1995).

**Table 2. Average level of soil pH, TIN, TP, K, Ca, and Mg from plots ( $n = 20$ ) amended with different levels of CLDM in 2002, 2003, 2004, and in 2005.**

Application rates	pH	TIN†	TP‡	K‡	Ca‡	Mg‡
(g kg <sup>-1</sup> )				(mg kg <sup>-1</sup> )		
Initial (all treatments)	5.9 ± 0.01	2.9 ± 1.5	20.6 ± 8.9	39.9 ± 11.6		
2002						
0	5.9 ± 0.006d§	0.16 ± 0.02c	5.08 ± 0.81a	3.6 ± 0.6a	105 ± 5.4b	4.3 ± 2.6b
250	7.1 ± 0.1c	0.67 ± 0.44b	0.17 ± 0.13b	0.9 ± 0.1c	1962 ± 25.8a	11.9 ± 0.7a
500	7.4 ± 0.005b	0.91 ± 0.24ab	0.13 ± 0.02b	2.8 ± 1.4a	2040 ± 29.1a	13.6 ± 1.1a
750	7.4 ± 0.00b	1.34 ± 0.12a	0.06 ± 0.02b	1.8 ± 1.0bc	2008 ± 87.1a	14.6 ± 1.7a
1000	7.5 ± 0.06a	0.87 ± 0.13b	0.14 ± 0.04b	2.5 ± 0.7abc	2030 ± 9.2a	14.7 ± 0.6a
LSD (0.05)	0.11	0.44	4.53	1.60	78.10	2.80
2003						
0	5.46 ± 0.08d	0.26 ± 0.01c	6.69 ± 0.01a	21.4 ± 2.8c	348 ± 40.3c	15.1 ± 0.84d
250	7.35 ± 0.10c	0.71 ± 0.44b	1.11 ± 0.21b	41.5 ± 13.4a	6534 ± 10.5ab	61.7 ± 5.6c
500	7.62 ± 0.08b	0.96 ± 0.19b	1.99 ± 0.14b	41.9 ± 11.4a	6679 ± 32.84a	86.3 ± 9.5a
750	7.67 ± 0.08b	1.40 ± 0.14a	1.69 ± 0.19b	36.5 ± 8.1ab	6564 ± 45.0a	92.9 ± 12.9a
1000	7.77 ± 0.05a	0.91 ± 0.13b0.43	1.61 ± 0.31b	27.9 ± 3.8bc	6236 ± 44.6b	74.9 ± 86b
LSD (0.05)	0.09	0.42	4.79	10.6	155.01	10.11
2004						
0	5.9 ± 0.69b	2.77 ± 0.19b	2.26 ± 0.82a	19.3 ± .1a	173 ± 9.1b	4.6 ± 1.5d
250	7.5 ± 0.08a	61.85 ± 1.5a	0.08 ± 0.01b	15.9 ± 1.2ab	1268 ± 7.8a	7.2 ± 0.8c
500	7.8 ± 0.06a	21.59 ± 5.26b	0.04 ± 0.01b	5.0 ± 1.0ab	1160 ± 9.8a	8.4 ± 1.1bc
750	7.7 ± 0.11a	28.16 ± 3.28ab	0.06 ± 0.01b	2.8 ± 0.3b	1155 ± 5.5a	10.4 ± 0.6ab
1000	7.8 ± 0.04a	26.50 ± 6.58b	0.07 ± 0.04b	6.2 ± 0.4ab	1155 ± 10.4a	12.7 ± 2.2a
LSD (0.05)	0.57	34.56	2.29	16.2	117.0	2.5
2005						
0	5.5 ± 0.77b	2.36 ± 0.67b	6.99 ± 0.98a	3.48 ± 0.8b	44.7 ± 8.3c	1.9 ± 1.4b
250	6.8 ± 0.96ab	2.32 ± 0.57b	3.15 ± 4.31ab	1.30 ± 0.4b	174 ± 2.8b	1.9 ± 1.4b
500	7.4 ± 0.02a	24.46 ± 13.32b	0.32 ± 0.05b	2.56 ± 0.57b	156 ± 2.6b	2.7 ± 1.8ab
750	7.3 ± 0.02a	29.26 ± 3.36a	0.18 ± 0.01b	14.25 ± 0.78a	318 ± 10.5a	8.8 ± 2.7a
1000	7.5 ± 0.02a	12.47 ± 7.83ab	0.11 ± 0.04b	3.06 ± 0.01b	301 ± 12.8a	4.8 ± 1.7ab
LSD (0.05)	1.42	18.20	5.11	10.1	313.7	6.14

† Extracted with 2 N KCl.

‡ Extracted with double acids (0.05 N HCl in 0.025 N H<sub>2</sub>SO<sub>4</sub>) as described by Mehlich (1953).§ Means in each column for each year with common letter(s) are not significantly different at  $p \leq 0.05$ .

plots with CLDM) values of 7.4, 7.6, 7.7, and 7.2 were higher than plots with no CLDM (5.9, 5.5, 5.9, and 5.5) in 2002, 2003, 2004, and 2005, respectively (Table 2). Soil test values for TIN in 2004 and 2005 showed an increasing trend when compared with their levels in 2002 and 2003 for soils treated with CLDM. The average increase of TIN in 2004 and 2005 in soils treated with CLDM (averaged across treatments) were 34.5 and 17.1 mg kg<sup>-1</sup> compared with 0.94 and 0.99 mg kg<sup>-1</sup> in 2002 and 2003, respectively. The levels of TP in soils that were treated with different levels of CLDM were consistently lower than the soil P values in plots with no CLDM application for all years. The average soil test values for TP in soils with no CLDM were 5.1, 6.7, 2.3, and 6.9 mg kg<sup>-1</sup> in 2002, 2003, 2004, and 2005, respectively. It must be noted that the soil tests values for TP and TIN in 2005 should not be construed as environmental problems. Their present soil tests values are well below levels considered to be harmful to the environment. Concern for losses of soil P by overland flow occur when soil TP exceeded 150 mg kg<sup>-1</sup> in the upper 20 cm of soil (Johnson and Eckert, 1995; Sharpley et al., 1996).

Average soil tests values for Mehlich 1-extracted Zn, Mn, Cu, Fe, and Al from plots treated with different levels of CLDM are shown Table 3. The levels of extractable Zn, Mn, Cu, Fe, and Al in soils were significantly reduced by CLDM application and this result was consistent for all years. With increasing application rates of CLDM, soil test values for extractable Zn, Mn, Cu, Fe, and Al were statistically comparable across years. These data suggest that applied CLDM, regardless of application rates, would not be a source of trace

metals in the soil (Table 3). The average levels of extractable Zn and Mn (averaged across years) in soils with CLDM treatments were significantly lower when compared to soils with no CLDM (Table 3). Similar trends and comparisons of results were noted for extractable Cu, Fe, and Al between plots with CLDM and plots with no CLDM application in 2002, 2003, 2004, and 2005. The average levels of Cu in soils without CLDM treatment were 0.45, 1.04, 0.14, and 0.02 mg kg<sup>-1</sup> compared with 0.002, 0.000, 0.002, and 0.009 mg kg<sup>-1</sup> in 2002, 2003, 2004, and 2005, respectively (Table 3). Our results were in good agreement with the general knowledge that perhaps the single direct benefit of liming is the reduction solubility of micronutrients, especially Al and Mn (Peavy et al., 1972). The CLDM that we used in this study could have provided the benefits that we normally would obtain from liming the field using commercially available lime.

### Herbage Mass of Bahiagrass

The herbage mass of BG over five harvests from 2003 to 2005 are shown in Table 4. Forage yield of BG was not affected by the interaction effects of time and levels of CLDM application. However, herbage mass of BG varied significantly ( $p \leq 0.001$ ) among plots with different levels of CLDM. The greatest average forage yield of 2391 ± 594 kg ha<sup>-1</sup> was from plots amended with 1000 g kg<sup>-1</sup> CLDM and the lowest average forage yield of 870 ± 236 kg ha<sup>-1</sup> was from the control plots (Table 4). Forage yield of BG from plots with 500, 750, and 1000 g kg<sup>-1</sup> of CLDM were comparable, and was

**Table 3.** Average level of Zn, Mn, Cu, Fe, and Al from plots ( $n = 20$ ) amended with different amounts of CLDM in 2002, 2003, 2004, and 2005.

Application rate	Zn†	Mn†	Cu†	Fe†	Al†
(g kg <sup>-1</sup> )	(mg kg <sup>-1</sup> )				
Initial (all treatments)	0.40 ± 0.3	1.30 ± 0.7	0.20 ± 0.1	4.90 ± 0.1	83.4 ± 17.1
2002					
0	0.69 ± 0.13a‡	2.86 ± 0.39a	0.45 ± 0.05a	15.81 ± 5.59a	87.23 ± 13.28a
250	0.01 ± 0.006b	0.35 ± 0.05b	0.001 ± 0.0005b	0.03 ± 0.01b	0.19 ± 0.24b
500	0.006 ± 0.001b	0.31 ± 0.01b	0.002 ± 0.001b	0.002 ± 0.001b	0.03 ± 0.02b
750	0.007 ± 0.0006b	0.25 ± 0.01b	0.002 ± 0.001b	0.002 ± 0.001b	0.01 ± 0.00b
1000	0.005 ± 0.00b	0.34 ± 0.04b	0.003 ± 0.001b	0.003 ± 0.000b	0.04 ± 0.02b
LSD (0.05)	0.10	0.32	0.04	4.56	10.80
2003					
0	0.93 ± 0.14a	2.66 ± 0.24a	1.04 ± 0.08a	23.17 ± 9.1a	46.31 ± 9.1a
250	0.13 ± 0.02c	0.91 ± 0.06b	0.00 ± 0.00b	0.19 ± 0.06b	0.58 ± 0.33b
500	0.23 ± 0.02b	0.93 ± 0.95bb	0.00 ± 0.00b	0.32 ± 0.06b	0.16 ± 0.15b
750	0.29 ± 0.04b	0.83 ± 0.09b	0.00 ± 0.00b	0.29 ± 0.07b	0.13 ± 0.03b
1000	0.24 ± 0.07b	1.08 ± 0.16b	0.00 ± 0.00b	0.36 ± 0.08b	0.14 ± 0.07b
LSD (0.05)	0.09	0.17	0.04	4.84	20.83
2004					
0	0.33 ± 0.04a	1.28 ± 0.11a	0.14 ± 0.11a	4.96 ± 0.78a	41.37 ± 7.14a
250	0.006 ± 0.001b	0.14 ± 0.11b	0.003 ± 0.001b	0.000 ± 0.00b	1.27 ± 0.18b
500	0.000 ± 0.000b	0.06 ± 0.02b	0.001 ± 0.0001b	0.000 ± 0.00b	1.08 ± 0.01b
750	0.000 ± 0.000b	0.07 ± 0.01b	0.002 ± 0.0001b	0.000 ± 0.00b	1.06 ± 0.04b
1000	0.000 ± 0.000b	0.08 ± 0.05b	0.002 ± 0.001b	0.000 ± 0.00b	1.03 ± 0.07b
LSD (0.05)	0.04	2.23	0.09	0.63	11.77
2005					
0	0.117 ± 0.06a	0.23 ± 0.15a	0.021 ± 0.011a	0.54 ± 0.30a	51.46 ± 7.14a
250	0.018 ± 0.02b	0.09 ± 0.01b	0.010 ± 0.007b	0.32 ± 0.05b	11.27 ± 9.18b
500	0.010 ± 0.01b	0.13 ± 0.01b	0.012 ± 0.001b	0.02 ± 0.01b	0.23 ± 0.03b
750	0.002 ± 0.00b	0.08 ± 0.02b	0.004 ± 0.001b	0.02 ± 0.00b	0.52 ± 0.01b
1000	0.004 ± 0.00b	0.07 ± 0.01b	0.013 ± 0.002b	0.01 ± 0.00b	0.49 ± 0.12b
LSD (0.05)	0.07	0.26	2.57	0.64	33.76

† Extracted with double acids (0.05 N HCl in 0.025 N H<sub>2</sub>SO<sub>4</sub>) as described by Mehlich (1953).‡ Means in each column for each year with common letter(s) are not significantly different at  $p \leq 0.05$ .

significantly greater than BG yield in plots without CLDM. The average forage yield increase due to CLDM amendments (averaged across treatments) was 139% over the control plots. Herbage mass of BG was increased by about 175, 164, and 139% as a result of 1000, 750, and 500 g kg<sup>-1</sup> of CLDM application, respectively, over the average forage yield of BG without CLDM. These data show the favorable influence that CLDM had on forage yield of BG during its early establishment in subtropical beef cattle pastures.

The average forage yield response of BG to different rates of CLDM application is shown in Fig. 3 and can be described by Eq. [1] (where  $x$  is the application rate of

dredged materials in g kg<sup>-1</sup>,  $R^2 = 0.99$ , and  $p \leq 0.0001$ ). Forage yield variability (99%) of BG during its establishment can be explained by the addition of CLDM.

$$\text{Forage yield (kg ha}^{-1}\text{)} = -106x^2 + 1015.8x - 39.2 \quad [1]$$

### Crude Protein Content

The crude protein of BG with and without CLDM in 2003, 2004, and 2005, and mean crude protein of BG are shown in Table 4. Results show a favorable influence of CLDM on crude protein content of BG during a 3 yr period (2003 to 2005). The crude protein of BG varied significantly ( $p \leq 0.001$ ) with varying levels of CLDM

**Table 4.** Mean herbage mass and crude protein content of bahiagrass as affected by varying levels of CLDM addition.

Application rates	Harvest dates					Mean
	4/02/2003	6/25/2003	4/25/2004	6/25/2004	3/20/2005	
(g kg <sup>-1</sup> )	kg ha <sup>-1</sup>					
Dry Matter Yield						
0	15.8 ± 0.6d†	1454.6 ± 83.4d	1262.8 ± 11.4c	804.3 ± 21.2c	814.4 ± 29.3b	870.4 ± 236.1b
250	173.4 ± 11.1c	2167.2 ± 36.9c	2780.3 ± 252.4b	1241.9 ± 46.5b	1426.9 ± 147.4b	1557.9 ± 428.0ab
500	461.4 ± 40.8b	2618.6 ± 115.3bc	3076.8 ± 130.9ab	1689.2 ± 25.9a	2547.0 ± 79.4a	2078.6 ± 440.7a
750	648.4 ± 14.1a	2879.6 ± 104.1ab	4109.0 ± 73.4a	1776.6 ± 125.9a	2066.8 ± 134.7a	2296.1 ± 548.9a
1000	276.8 ± 12.3c	3260.1 ± 51.5a	3803.9 ± 407.6ab	1954.4 ± 39.9a	2660.4 ± 104.5a	2391.1 ± 593.9a
n	20	20	20	20	20	
LSD (0.05)	118.7	481.5	1291.5	370.3	615.3	939.4
(g kg <sup>-1</sup> )	%					
Crude Protein Content						
0	—	9.3 ± 0.7b	7.1 ± 0.3a	6.6 ± 0.1a	6.3 ± 0.01d	7.3 ± 0.2c
250	—	12.6 ± 1.2ab	8.4 ± 0.8a	9.8 ± 0.4b	8.5 ± 0.2c	9.8 ± 0.5b
500	—	13.9 ± 2.0a	7.5 ± 0.3a	9.9 ± 0.3b	8.4 ± 0.4c	9.9 ± 0.6b
750	—	14.1 ± 2.4a	8.9 ± 0.7a	10.7 ± 0.01b	10.9 ± 0.5b	11.2 ± 0.6ab
1000	—	15.1 ± 2.2a	8.8 ± 0.3a	14.6 ± 0.4a	12.7 ± 0.1a	12.8 ± 1.2a
n		20	20	20	20	
LSD (0.05)		3.3	3.1	1.7	1.7	1.8

† Means in each column with common letter(s) are not significantly different at  $p \leq 0.05$ .

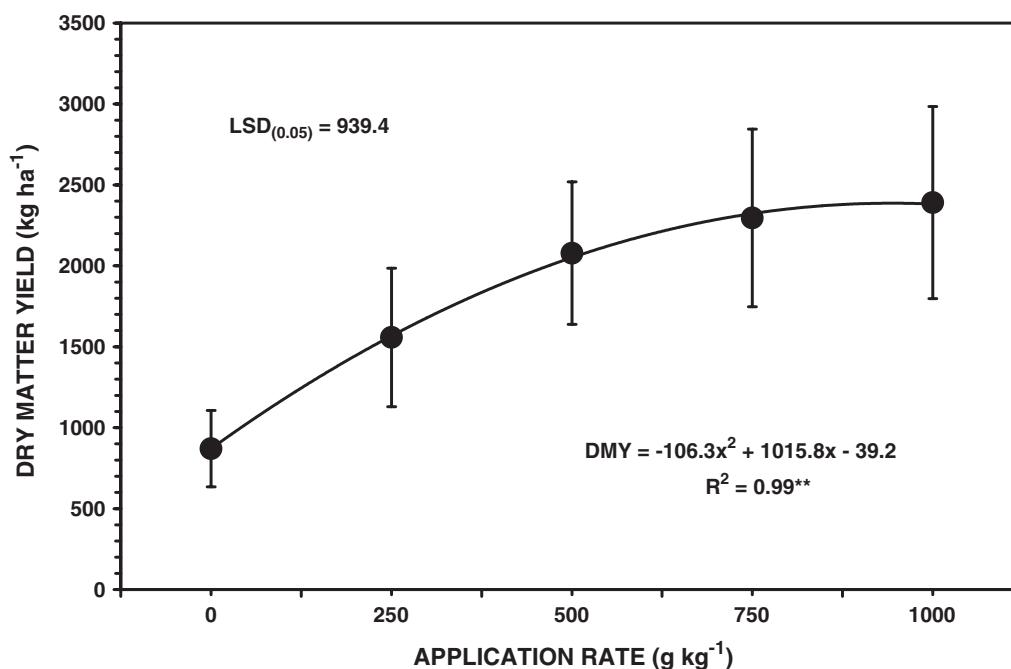


Fig. 3. Relationships between dry matter yield of BG and increasing rates of CLDM application.

applications. The tissues of BG with 1000 g kg<sup>-1</sup> of CLDM had the highest CP (12.8 ± 1.2%), whereas control plots had the lowest CP concentration of 7.3 ± 0.2%. The crude protein concentration of BG in plots with 250 g kg<sup>-1</sup> (9.8 ± 0.5%), 500 g kg<sup>-1</sup> (9.9 ± 0.6%), and 750 g kg<sup>-1</sup> (11.2 ± 0.6%) of CLDM were statistically comparable, but were significantly higher than that in the control plot (Table 4). The average crude protein of BG increased linearly with increasing rates of CLDM application (Fig. 4) and can be described by

Eq. [2] (where x is the application rate of dredged materials in g kg<sup>-1</sup>, R<sup>2</sup> = 0.94, and p ≤ 0.0001):

$$\text{Crude protein (\%)} = 1.24x + 6.48 \quad [2]$$

### Mineral Composition of Herbage Tissues

The mineral composition of BG that was grown in sandy soils of Sumter County was enhanced significantly (p ≤ 0.001) by CLDM addition (Table 5). Levels of

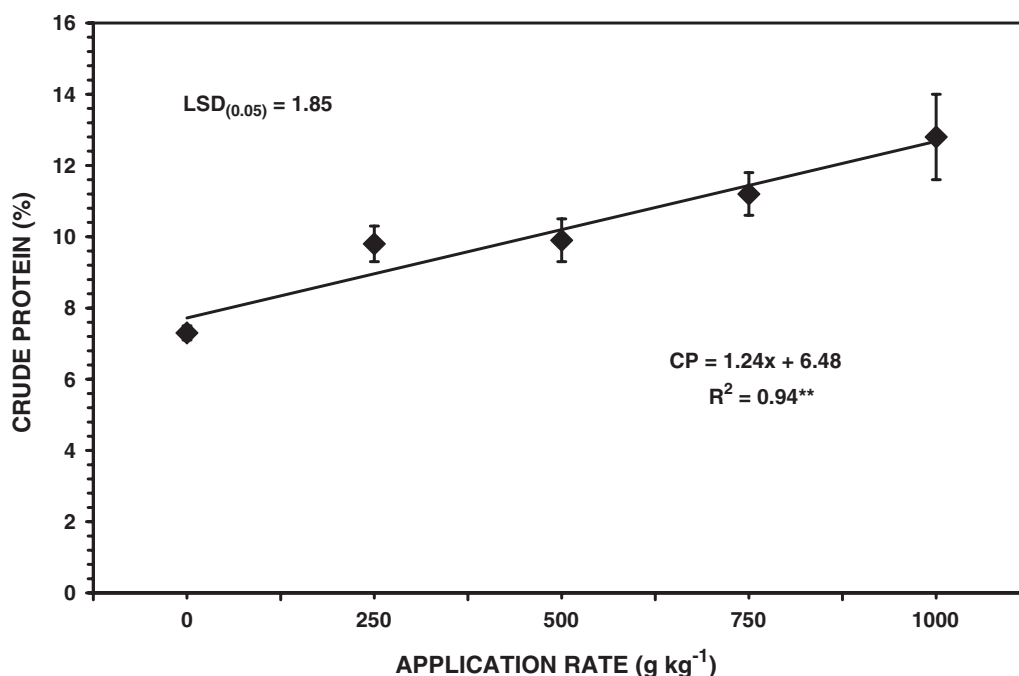


Fig. 4. Relationships between crude protein content of BG and increasing rates of CLDM application.

**Table 5. Average herbage tissue concentrations ( $n = 20$ ) of TP, TN, K, Ca, and Mg as affected by varying levels of CLDM addition.**

Application rate	TP†	TN‡	K†	Ca†	Mg†
(g kg <sup>-1</sup> )			mg kg <sup>-1</sup>		
0	2398 ± 57.3a§	10 630 ± 742d	10 471 ± 104.6a	8363 ± 1827c	1575 ± 308c
250	2393 ± 83.9a	14 277 ± 1862c	5577 ± 181.9b	10 072 ± 1867a	2176 ± 380b
500	2117 ± 9.2a	13 793 ± 1989c	8255 ± 151.7ab	9051 ± 1712bc	1732 ± 504c
750	2267 ± 83.9a	16 306 ± 2078b	7045 ± 259.2ab	9414 ± 2213ab	3240 ± 515a
1000	2597 ± 78.5a	19 239 ± 2313a	8944 ± 159.1ab	8911 ± 2385bc	2222 ± 496b
LSD (0.05)	634	1727	4539	865	381

† Nitric and perchloric acids digestion (Hanlon and Devore, 1989) analyzed using ICP.

‡ Sulfuric acid digestion; Kjeldahl method (Isaac and Johnson, 1976).

§ Means in each column with common letter(s) are not significantly different at  $p \leq 0.05$ .

TN, Ca, and Mg were remarkably increased as a result of CLDM addition. The average TP composition in herbage tissues of BG was not affected by CLDM application (Table 5). The levels of TN, K, Ca, and Mg in the tissues of BG were below the adequate levels of nutrients to attain 90 to 100% maximum yields, but their levels were above the deficiency range (Table 6), so additional nutrients from other sources (e.g., inorganic fertilizers) are still needed to sustain and maintain BG productivity at adequate nutrient levels. Bahiagrass applied with 750 g kg<sup>-1</sup> of CLDM had the overall highest mineral composition for TN, Ca, and Mg. This rate of CLDM addition improved the mineral composition of BG for TN, Ca, and Mg by 53, 13, and 106%, respectively, when compared with herbage tissues of BG in plots with 0 g kg<sup>-1</sup> of CLDM (Table 5).

Concentrations of Al, Fe, Mn, Zn, and Si in BG herbage tissues were significantly reduced as a result of CLDM application, whereas tissue levels of Cu and Pb were not affected (Table 7). The levels Mn, Zn, and Cu were neither at a deficit nor high enough to create toxic effects on plant growth. The lowering effects of applied CLDM on herbage tissue concentrations of micronutrients may not create adverse plant growth effect because the levels of these micronutrients were kept slightly above the critical levels to avoid further reduction in yield due to a low supply of nutrients (Table 6).

The overall mineral compositions of BG, especially for TN, TP, K, Ca, and Mg, were not improved by 250 g kg<sup>-1</sup> CLDM addition, but were enhanced significantly by the addition of 500 g kg<sup>-1</sup> and 750 g kg<sup>-1</sup> CLDM. However, application of 1000 g kg<sup>-1</sup> CLDM did not further increase the concentrations of TN, TP, K, Ca, Mg, Al, Fe, Mn, Cu, Pb, and Si in BG tissues (Tables 5 and 7).

**Table 6. Nutrient Criteria for Warm Season Grasses.**

Element	Nutrient ranges				Reference
	Deficient	Critical	Adequate	High	
	mg kg <sup>-1</sup>				
TN†	<15 000	18 000	25 000	>34 000	Burton, 1954; Adams et al., 1967
TP	<1600	2000	2600	>4000	Fisher and Caldwell, 1959
K	<14 000	15 000	18 000	>23 000	Jordan et al., 1966
Ca	2500	3750	17 500	30 000	Jones, 1967
Mg	2000	2500	6500	15 000	Jones, 1967
Mn	<20	20–30	31–100	250	Jones, 1967
Zn	<11	11–20	21–70	70–100	Jones, 1967
Cu	<6	7–10	11–30	31–50	Jones, 1967

† Sulfuric acid digestion; Kjeldahl method (Isaac and Johnson, 1976).

## DISCUSSION

Results of this study have demonstrated the favorable and beneficial effects of added CLDM on the growth of BG and soil quality in beef cattle pasture fields. Sediments that were dredged from LP have high CaCO<sub>3</sub> content (82%) and when these materials were incorporated into existing topsoil, had similar effects as would liming the field. Sediments with high CaCO<sub>3</sub> improve both the physical and chemical conditions of soils under subtropical pastures. It should be noted that Ca is not the only key to reducing soil acidity. Without the carbonate (CO<sub>3</sub><sup>-2</sup>), the soil would still contain the acid ion and pH would not change. The lake-dredged materials (82% CaCO<sub>3</sub>) that were used in this study can be an alternative for commercial liming product for agricultural use. Perhaps the single largest direct benefit of liming is the reduction in acidity and increased solubility of Al and Mn (Peevy et al., 1972). Addition of CLDM resulted in higher soil pH than those plots with 0 g kg<sup>-1</sup> CLDM. Higher pH values in soils with CLDM would favor hydrolysis reactions for Ca and Mg which increase the plant availability of these two nutrients. Higher soil pH values may well inactivate Al, Mn, Cu, and Fe. Our results have shown that the levels of soil Mn, Cu, Fe, and Al were significantly lowered by the addition of CLDM (Tisdale and Nelson, 1975).

Some of the indirect benefits of liming pasture fields would include enhancing nutrient availability, nitrification, N fixation, and improving soil physical conditions, among others (Russel, 1973; Tisdale and Nelson, 1975; Nelson, 1980). Although CLDM contained relatively low nutritional values (Table 1), its effect on BG in the beef pasture field was remarkable. Bahiagrass, during its early establishment, requires low levels of nutrients. The levels of N, P, and the liming effects of CLDM were enough to promote and sustain the early establishment of BG in the beef pasture field. A similar study on beneficial use of dredged materials in east central Florida was reported by Sigua et al. (2000). Patel et al. (2001) reported that grasses grown in muck-amended topsoil had adequate and comparable nutrient levels with grasses grown in heavily fertilized and well maintained golf course soils. They also reported that horticultural studies showed encouraging results of several plant species, such as the holly (*Ilex cornuta*), liriopie (*Liriope muscari*), oyster plant (*Rhoeo spathacea*) and bermudagrass (*Cynodon dactylon*). In the present study, the level of N in the tissues of BG was below the adequate level to attain 90 to 100% maximum yield, but the level of N was

**Table 7. Average herbage tissue concentrations ( $n = 20$ ) of Al, Fe, Mn, Zn, Cu, Pb, and Si as affected by varying levels of CLDM addition.**

Application Rate	Al <sup>†</sup>	Fe <sup>†</sup>	Mn <sup>†</sup>	Zn <sup>†</sup>	Cu <sup>†</sup>	Pb <sup>†</sup>	Si <sup>†</sup>
(g kg <sup>-1</sup> )				mg kg <sup>-1</sup>			
0	73.4 ± 9.2a‡	386.7 ± 54.8a	79.5 ± 2.8a	25.9 ± 5.2a	7.1 ± 1.3a	0.085 ± 0.17a	144.6 ± 10.0bc
250	45.1 ± 6.6b	182.9 ± 77.6ab	47.2 ± 7.7b	19.3 ± 2.3b	6.2 ± 0.7a	0.035 ± 0.07a	181.2 ± 5.5a
500	39.4 ± 7.1b	146.7 ± 30.1b	22.8 ± 4.8c	20.4 ± 2.4b	6.9 ± 1.3a	0.092 ± 0.10a	106.6 ± 9.8d
750	39.2 ± 6.3b	137.4 ± 13.7b	68.8 ± 9.5ab	20.7 ± 2.3b	6.1 ± 0.9a	0.000 ± 0.00a	169.2 ± 4.9ab
1000	42.2 ± 6.9b	136.9 ± 98.5b	14.7 ± 3.5c	23.9 ± 1.3ab	7.3 ± 1.2a	0.000 ± 0.00a	123.7 ± 6.3dc
LSD (0.05)	9.4	235	23.9	4.8	1.2	0.16	34.7

<sup>†</sup> Nitric and perchloric acids digestion (Hanlon and Devore, 1989) analyzed using ICP spectroscopy.

<sup>‡</sup> Means in each column with common letter(s) are not significantly different at  $p \leq 0.05$ .

above the deficiency range (Table 6). Additional N from other sources (e.g., inorganic fertilizers) are still needed to sustain and maintain BG productivity at adequate nutrient levels. Bahiagrass applied with 750 g kg<sup>-1</sup> of CLDM had the overall highest nutrient composition for TN, Ca, and Mg. This rate of CLDM addition had improved the nutritional composition of BG for N by 53% when compared with herbage tissues of BG in plots with no CLDM.

Penetration resistance was lowered significantly by the application of CLDM. The least compacted soils were observed from plots with 750 g kg<sup>-1</sup> CLDM, while the most compacted soils were from the control plots (0 g kg<sup>-1</sup> CLDM). These results have shown the favorable influence that CLDM had on penetration resistance. Penetration resistance of soil treated with CLDM have values well within the "good" range of root development or penetration. Penetration resistance of about  $1035 \times 10^3$  Pa in soils could result to a root penetration reduction of about 50%, while penetration resistance of greater than  $1380 \times 10^3$  Pa may result in 80 to 90% root penetration reduction (Fig. 2). The higher rates of CLDM application may have had improved soil structure and soil tilth which can promote better water holding capacity, provide sufficient aeration, create more friable soils, and potentially stimulate root development. The compaction of agricultural soils is a serious problem and growing concern because the productive capacity of the land could be seriously reduced. A compacted layer within the soil profile may restrict root growth and access to water and nutrients (Follet and Wilkinson, 1995). Root penetration tended to decrease with penetration resistance as shown in Fig. 2. Penetration resistance of greater than  $1380 \times 10^3$  Pa may trigger poor root development if not corrected properly. The use of a penetrometer, which is designed to mimic a plant root, is one way of monitoring soil compaction. The structure of fine-textured (typic quartzipsamments) soils in the study area has shown improvement as a result of CLDM addition. This is largely the result of an increase in the organic matter content and to a lesser extent to the flocculation of Ca-saturated colloids. Application of CLDM may have promoted intense biological activity, fixing more N to soil microorganisms, and promoting release of component elements as plant residues rapidly decompose (Follet and Wilkinson, 1995; Pearson and Hoveland, 1974).

Another equally important beneficial use of CLDM is enhancing crude protein and mineral composition of BG. Results have shown the favorable influence that CLDM had on crude protein and nutritive values of BG during its

early establishment. The crude protein of BG varied significantly with varying levels of CLDM applications. The tissues of BG grown in plots applied with 1000 g kg<sup>-1</sup> of CLDM had the greatest crude protein content, whereas the control plots yielded the lowest crude protein content in BG. Similar results on the effect of lime application on BG were reported by Janak (1999). The lime-treated (4480 kg ha<sup>-1</sup>) BG in Texas showed an increase in crude protein (11%) and an increase forage yield of 823 kg ha<sup>-1</sup> over the untreated BG. He reported further that liming forages proved to be economical, showing an \$8.00 ha<sup>-1</sup> (\$18.85 acre<sup>-1</sup>) return over the control.

Herbage tissue contents of TN, TP, K, Ca, and Mg were remarkably increased as a result of CLDM application. Levels of Mn, Cu, Fe, and Al in herbage tissues of BG were likewise favored by varying levels of CLDM. The physiological functions performed by Ca in plants are not clearly defined, but it has been suggested that Ca favors the formation of and increases the protein content of mitochondria. Calcium is especially important in maintaining the organization of the protoplasm and providing the cement of cell walls as Ca pectate (Miller and Heichel, 1995). The role played by mitochondria in aerobic respiration, indicates that there may be a direct relationship between Ca and ion uptake in general. Calcium can be considered to be related to protein synthesis by its enhancement of the uptake of N (Tisdale and Nelson, 1975). The amount of soil Ca and Mg among plots with CLDM were significantly higher than that in the control plots. Addition of CLDM increased the levels of Ca and Mg by about 784 and 312%, respectively, over 4 yr (2002, 2003, 2004, and 2005) when compared with the level of soil Ca and Mg among plots with no CLDM application.

## CONCLUSIONS

Beneficial uses of carbonatic dredged materials from Lake Panasoffkee, Florida are both economical and environmental. Land application of CLDM may provide substantial benefits that will enhance the environment, community, and society. The ability to reuse CLDM for agricultural purposes is important because it reduces offshore disposal and provides an alternative to disposal of the materials in landfills that are already overtaxed. Results of our study have demonstrated the favorable and beneficial effects of added CLDM on the early establishment of BG and soil quality in pasture fields. Bahiagrass in plots that were treated with CLDM had significantly higher forage yield and crude protein content when compared with those BG in the control plots.

Carbonatic lake-dredged materials can be used as soil amendments (lime and fertilizer) for early establishment of BG in beef cattle pastures. The heavy and trace metal contents of these materials were below the PEL and TEL (Table 1). As such, the agricultural or livestock industry could utilize these CLDM to produce forages. Our results have demonstrated the beneficial use of uncontaminated carbonatic lake-dredged materials as a cheaper alternative for commercial liming products for agricultural use. The amount of Ca (as  $\text{CaCO}_3$ ) in CLDM (82%) was even higher than the amount of  $\text{CaCO}_3$  in calcitic limestone (70%) and dolomitic limestone (58%). Calcitic limestone and dolomitic limestone are two of the leading liming materials available commercially. Additionally, these materials (CLDM) can be obtained at little or no cost to the farmers or landowners in southern Florida. Therefore, carbonatic lake-dredged materials should be regarded as a beneficial resource, as a part of the ecological system. Although our results have demonstrated the promising effects of added CLDM on the early establishment of BG in pasture fields, further studies are still needed not only in beef cattle pastures of Florida, but also in other areas of the world with similar climatic conditions to determine whether the environmental and ecological implications of CLDM application are satisfied over the longer term. Planning at the national and local levels must be proactive in identifying potential beneficial uses of dredge materials.

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